# NONWOVEN FABRICS FOR WIPING APPLICATIONS

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The invention relates to fabrics for use in wiping liquids and/or particles from surfaces.

### 2. Description of the Related Art

Certain types of fabrics are used to wipe surfaces. This could range from merely wiping up liquids from a kitchen counter in the home to wiping surfaces in cleanrooms where it is critical that preferably no particles or only a very minimum level of particles remain on the wiped surface.

It has been believed that the best fabrics for critical cleanroom applications are knitted fabrics with either sealed or unsealed edges. Such fabrics were characterized by having moderate sorptive properties and were considered "clean" in that they had low levels of releasable particles. By releasable particles is meant particles which are preexisting and are released from the fabric as well as newly generated particles that are formed through the adminisration of stress to the actual wiping fabric. These supposedly superior fabrics exhibited their desirable properties based on tests of sorption and number of releasable particles. Although nonwovens have been used in some cleanroom applications, for example, Sontara®, a registered trademark of E.I. du Pont de Nemours and Company (DuPont), they were not deemed good candidates for especially critical cleanroom applications. This was because such nonwovens were deemed relatively "dirty" versus laundered knits based on these static tests, which do not test actual performance in wiping. Such nonwovens have been used in cleanrooms rated as Class 100 or higher in accordance with Federal Standard 209E, September 11, 1992, however, typically they have not been fully accepted as suitable for critical cleanroom applications rated as Class 10 or lower (i.e., cleaner). The standard shows the maximum number of airborne particulates at a given size. For example, Class 100 has a maximum of 100 particles per cubic foot at a size of 0.5 micrometer, whereas Class 10 has a maximum of 10 particles per cubic foot at the same size. However, it would be desirable to use such nonwoven fabrics in view of their very low cost opposite the knitted fabrics.

DuPont had made efforts to develop an inexpensive nonwoven fabric, especially for the critical cleanroom wiping applications. The fabrics, such as Sontara®, were typically made by hydroentangling as disclosed in U.S. 3,485,706 to Evans, which is incorporated by reference. Hydroentangled fabrics made of 100% polyester were found not suitable for critical cleanroom applications

because they were too hydrophobic. Hydrophilicity can be imparted to fabrics by laundering whereby the fabrics receive surfactants, but hydroentangled fabrics were not typically durable enough to withstand such launderings. Laundering would cause the fabrics to become fuzzy and to disentangle. When binders were added to the hydroentangled fabrics to increase durability, the fabrics were not sufficiently hydrophilic for wiping applications.

## SUMMARY OF THE INVENTION

This invention is directed to a wiping material comprising a polyester nonwoven fabric that has been cleanroom laundered and is adapted for use in cleanrooms rated as Class 10 or cleaner. The invention is also directed to a method of using a nonwoven fabric for wiping in cleanrooms rated as Class 10 or cleaner.

## DETAILED DESCRIPTION OF THE INVENTION

It has been found that evaluating fabrics using newly developed dynamic tests, which correlate with the actual wiping process, shows that certain nonwoven fabrics, based on Sontara®, for example, equal or exceed the performance of the knitted fabrics. Moreover, it has been found that cleanroom laundering of certain types of Sontara® fabrics imparts surprisingly exceptional wiping properties.

There are least three factors important in the removal of a liquid from a critical surface using a wiper, whether that liquid is added deliberately to the surface for the purpose of cleaning or whether it is present merely as the result of a spill. First is the dynamic efficiency with which a wiper is capable of sorbing liquids. Second, there is the number of particles already present in the spill (or on the surface being wiped) and the extent to which those particles are removed during the wiping process. Third, there is the very real concern regarding particles and fibers, which the wiper itself may leave behind on the surface being wiped.

It has been found that cleanroom wipers made from fabrics that have an exceptional ability to "wipe the surface dry" leave the wiped surface cleaner than those which do not, since the residual contamination resulting from a spill typically is suspended in the liquid phase left behind on the wiped surface. The conclusion is that wipe-dry is not merely a desirable feature in a cleanroom wiping material from a housekeeping point of view, but is a critical feature in wiping up spills of dirty liquids and, by extension, in the removal of particles from surfaces.

It has been determined that the inherent cleanliness of wiping materials (a property predicated upon the burden of particles already present in the wiper) is of less importance in selecting wiping materials for removing liquids from surfaces than is the ability of those same wiping materials to wipe surfaces dry.

## CONVENTIONAL TEST METHODS

Many tests exist for assessing the suitability of fabrics for their use as cleanroom wiping materials. Some procedures address the functional characteristics of wiping materials with a view toward quantifying their sorptive properties, specifically, the rate and capacity with which wipers can sorb liquids. Other tests are concerned with properties related to the cleanliness of wipers, especially the determination of the number of particles or fibers that are present or which can be generated from wipers in response to applied stress.

Some of the most used among the tests for quantifying sorptive properties of wiping materials are those found in Recommended Practice RP-004.2 "Evaluating Wiping Materials Used in Cleanrooms and Other Controlled Environments," IES-RP-CC004.2, Institute of Environmental Sciences, 940 East Northwest Highway, Mount Prospect, IL 60056 (1992). That test is used in this study for quantifying the intrinsic sorptive capacities of the wiping materials evaluated.

Other methods, however, also exist which include:

INDA Standard Test 10.1-95, "Measuring Absorbency Time, Absorbency Capacity, and Wicking Rate," INDA (Association of the Nonwoven Fabrics Industry), 1300 Crescent Green, Suite 125, Cary, NC 27511, which describes a basket test and a wicking rate test.

"Wipers Used in Clean Rooms and Controlled Environments," IES-RP-CC004-87-T, Institute of Environmental Sciences, 940 East Northeast Highway, Mount Prospect, IL 60056 (1987), which describes a time to half sorption test.

AATCC Method No. 79-1992, "Absorbency of Bleached Textiles," AATCC Technical Manual, Association of Textile Chemists and Colorists, 68, 106 (1993), which describes a water drop test.

Miller, B. and Tyomkin, I., Textile Research Journal, 54, 708 (1984), and Painter, E.V., TAPPI, 68(12), 54 (1985) which describe a demand absorbency test (GATS).

While all of these tests permit differentiation of wiping materials (also referred to as wipers) according to their ability to sorb liquids, the tests describe a substantially static property of the wiper. None of them addresses, directly or indirectly, the ability of a wiper to remove liquid from a surface in a dynamic

fashion, that is, under pressure and conditions similar to those which might exist during manual wiping operations.

During the manual wiping up of a pool of fluid with a wiper, liquid is sorbed into the fabric. At the same time, however, other forces may act counter to this sorptive process. For example, the pressure exerted during wiping can either retard sorption or force already sorbed liquid out of the wiper. Also, surface tension differences may affect the liquid distribution between the wiper and the surface. Not all wipers can "wipe dry" even when their sorptive capacities, as determined by static tests such as those mentioned above, are not exceeded. This is particularly true for items made from hydrophobic synthetic polymers, which frequently leave trails or droplets of water behind in the wake of manual wiping operations.

In assessing wiping materials for cleanliness with respect to particles, the primary focus has generally been directed toward determining how many particles are present in or on the wiper or how many particles are released from the wiper in response to the administration of stress. Although in some of the early tests, wipers were tested in a dry state, the currently accepted practice is that the generation, collection and enumeration of particles be accomplished with the wipers in a wetted condition.

The following two methods are among the most useful of these wet tests. The first is a test for the number of readily releasable particles found on a wiper as set forth in Mattina, C. F., and Paley, S. J., "Assessing Wiping Materials for their Potential to Contribute Particles to Clean Environments: A Novel Approach," Particles in Liquids and Gases 2: Detection Characterization and Control, K. L. Mittal, editor, 117-128, Plenum Publishing Corporation, New York (1990). A second method involves the construction of a characteristic curve for each wiper as presented in Mattina, C. F., and Paley, S. J., "Assessing Wiping Materials for their Potential to Contribute Particles to Clean Environments: Constructing the Stress Strain Curves", Journal of the IES, <u>34</u>(5), 21 (1991) and in Oathout, J. Marshall and Mattina, Charles F., "A Comparison of Commercial Cleanroom Wiping Materials for Properties Related to Functionality and to Cleanliness," Journal of the IES, <u>38</u>(1), 41 (1995). These methods show how particles are generated in response to the application of known amounts of mechanical energy.

Yet another test, in which wipers are shaken up in a liquid on a biaxial shaker, as described in "Wipers Used in Clean Rooms and Controlled Environments," IES-RP-CC004-87-T, Institute of Environmental Sciences, 940 East Northeast Highway, Mount Prospect, IL 60056 (1987) also enjoys some popularity. This was modified in Atterbury, O., Bhattacharjee, H. R., Cooper, D. W., Dominique, J. R., Paley, S. J., Siegerman, H., "Evaluating Cleanroom Wipers

to Establish Performance Benchmarks, Micro, 51, 5 (1998) to include the addition of a surfactant followed by subsequent enumeration of the particles by scanning electron microscopy. This is said to simulate the stresses encountered during actual use better than the test for releasable particles noted above, but the amount of energy imparted through such shaking is unknown.

All of these testing methods are incorporated herein by reference.

## INVENTIVE TEST METHODS

There are only a few methods for evaluating the ability of a fabric to wipe a surface dry. Macfarlane, K., "Assessing Wipe Performance," Proceedings of IDEA '98 (INDA), 12.1 (1998) describes such a test. Some aspects of the Macfarlane test were used to develop the dynamic wiping efficiency test, as described below.

Mattina, C. F., McBride, J., Nobile, D. and Turner, K., "The Cleanliness of Wiped Surfaces: Particles Left Behind as a Function of Wiper and Volume of Solvent Used," Proceedings, CleanRooms '96 East, 183 (1996) presents data for particles originating from the wipers that remain on a clean surface when those wipers are challenged with different increments of their sorptive capacities. Relatively few particles are left behind when the wipers are challenged with volumes of liquid less than their sorptive capacities but--in stark contrast--all of the wipers were found to leave behind significant numbers of particles when their capacities were exceeded. Surprisingly, regardless of composition or construction, the number of particles left behind by wipers becomes remarkably similar once the challenges exceed the sorptive capacities of the wipers. Conventional wisdom would suggest that the so-called "clean" fabrics would leave behind proportionately fewer particles than the so-called "dirty" fabrics. However, it was observed that the ability of wipers to remove liquids from the surface is very important, since it is only when liquid is left behind by a wiper that particles are left in excessive numbers.

Some elements of the method of Mattina, et al. were used in the development of a second test to determine the numbers of particles that remain on a surface after dynamic wiping. When particles from an outside source are deliberately included in the liquid challenge, the test is referred to as the Particle Removal Ability (PRA) test.

The details of the new test methods are explained below.

Dynamic Wiping Efficiency

As noted above, the Macfarlane apparatus and procedure was modified in several ways. A wiping speed of 25 cm/s was used as being more realistic of actual

wiping than 50 cm/s. A 50-cm stainless steel tray was used whose inside long dimension of 45 cm provided a free distance of about 36 cm in front of a 1-kg sled. The sled's footprint had dimensions of 114 mm on an edge to accommodate wiping materials that had been quarter-folded from their most common size of 229 mm by 229 mm (9 inches by 9 inches).

Instead of a single challenge consisting of 1 mL of water, many different volumes were used up to roughly 130% of the sorptive capacities of wipers as measured by their intrinsic sorptive capacity. In this fashion, if desired, an efficiency curve could be constructed for any wiper, either as a function of the volume of the challenge, or as a function of the sorptive capacity of the wiper.

Rather than placing the fabric and sled directly onto the liquid pool and then allowing time to elapse before beginning the traverse, the liquid challenge was placed in front of the sled which was pulled into and through the pool, which more closely resembles the phenomenon of wiping up real spills.

The following equipment was used:

balance: top loading, shielded, 0.01-g readability tray:

stainless steel, inside dimensions 45 cm x 28 cm x 7 cm, sufficient size to contain water where particles are enumerated; see below for description

sled: stainless steel, 1 kg, 114 mm x 114 mm base; a curved leading edge on the base of the sled forms a lip to which the quarter-folded sample is attached using a spring-loaded clip. Two stainless steel screws are affixed to either outboard edge of the sled in the leading curved edge.

dispenser: Brinkmann Bottletop Buret, Model 25, for reproducible and accurate delivery of volumes of liquid

water: for convenience (but not required), the same clean water was used here as for where particles are enumerated; see below for description

apparatus: a polyester string is attached to the sled at the stainless steel screws, forming a yoke. A second polyester string (about 4 ft long) is attached at the midpoint of the yoke. The string is used to pull the sled by hand at a rate of about 25 cm/sec.

It is understood that equivalent or appropriately similar equipment to that described above could be used.

The procedure was as follows:

1. Quarter-fold a single ply of wiping material (nominally, 229 by 229 mm) and determine its dry mass, $M_d$, to the nearest 0.01 g.

2. Clip the quarter-folded wiper to the sled so that the single convex fold is at the leading edge.

3. Position the sled at one end of the stainless steel tray with the leading edge perpendicular to the axis of the long dimension of the tray.
4. If the intrinsic sorptive capacity, $A_i$, of a wiper is not already known, determine it on a separate ply of the material using the procedure of IEST - RP-CC004.2 as referenced above. From the calculated $A_i$ and the measured mass of each wiper, calculate the per-ply capacity $A_{ip}$ [mL/g] for each wiper. This quantity is needed in order to know what fraction of the sorptive capacity is represented by each volume of liquid challenge.
5. Using the dispenser, place the desired volumetric challenge of water, $v_c$, into the tray at a point about 1-2 few centimeters in front of the leading edge of the sled.
6. Using the string, pull the sled at a rate of about 25 cm/s through the water and along the long axis of the tray, a distance of approximately 36 cm (the free distance in front of the sled, allowing for room to lift the sled and wiper without hitting the lip of the tray). Remove the sled and wiper from the tray by lifting the sled with the string, with a smooth and rapid motion.
7. Remove the folded wiper from the sled, determine its wetted mass, $m_w$, and, by difference, the mass of water sorbed. Calculate, using the density of water (0.997 g/mL at 25°) the volume of water sorbed, $v_s$. Calculate the dynamic wiping efficiency, DWE, by dividing the volume of water sorbed, $v_s$, by the volume of the challenge, $v_c$, and converting to a percentage:

$$DWE = 100\ [(m_w - m_d)/0.997]/v_c = 100\ v_s/v_c$$

DWE can be presented as a function of the absolute volume of the challenge, $v_c$, and as a function of the challenge relative to $A_i$. The relative challenge is expressed as $100\ v_c/A_{ip}$.

Particle Removal Ability

To measure the ability of wipers to remove particles from surfaces, the test for dynamic wiping efficiency was combined with certain elements of the test described by Mattina, et al., above, for quantifying the number of particles left behind on a surface which originate with the wiper. Differences were the addition to the liquid challenge of a known number of poly(styrene) spheres and also the use of quarter-folded samples instead of unfolded samples. The result from this procedure was termed "particle removal ability," or PRA. For all practical purposes, the tests for DWE and PRA is one test, performed either with or without particles added to the liquid challenge.

A quarter-folded wiper (attached as described above to the underside of the sled and pulled across a clean stainless steel pan) was drawn through a challenge of water in which were dispersed poly(styrene) spheres of known dimension and concentration. After the sled and fabric were removed from the tray, the particles and liquid remaining on the tray were dispersed in clean water and counted with a discrete-particle counter. The particles left behind from the challenge were presented versus the volume of the liquid challenge, $v_c$, and versus the challenge expressed as a percentage of the fabric's sorptive capacity, $100\ v_c/A_{ip}$.

The water challenge was dosed with a fairly large number of spheres, (about $10 \times 10^6$), so that, after wiping and subsequent dilution, a sufficient number of the spheres would remain so as to be distinguishable from the background count of the clean water. For convenience, spheres with diameters of 1.59 micrometers were chosen so that measurements could be safely made in the 1.0 to 3.0 micrometer channel of the discrete-particle counter. The spheres were deposited using a micro-liter syringe, the plunger of which was incrementally adjusted until $10 \times 10^6$ spheres could be delivered reproducibly. This portion of the work was done in a horizontal, laminar-flow clean workstation (Atmos Tech, Model 6302). The air produced by this work station, which was monitored in use using a discrete-particle counter (Met One, Model 227) consistently conformed to the requirements of Class 10 (at 0.5 micrometer) or cleaner as defined in Federal Standard 209E, "Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones," 11 September 1992.

In addition to the materials and equipment described above, the following were used:

spheres: poly(styrene), particle-deposition standards, Duke Scientific Surf-Cal Scanner, PD 1600, 1.59 micrometers at a concentration of $3 \times 10^8$/mL

syringe: Hamilton, 50 microliters

water: Millipore system consisting of a reverse osmosis unit (Milli-RO 10 Plus), an arrangement of filters and ion exchange beds Milli-Q UF Plus), and a 0.2 micrometer filter (Millipak 40) at the point of use

particle counter: PMS Microlaser Particle Spectrometer (μLPS) fitted with a Corrosive Liquid Sampler, Model 200

The procedure was as follows:

1. Clean the stainless steel pan and measure the background concentration of particles (1.0 to 3.0 micrometers) in a 1000-mL volume of water placed therein.

2. Quarter-fold a single ply of wiping material (nominally 229 by 229 mm) and determine its mass, $m_d$, to the nearest 0.01 g.

3. Clip the quarter-folded wiper to the sled so that single convex fold is the leading edge.

4. Position the sled at one end of the stainless steel tray with the leading edge perpendicular to the axis of the long dimension of the tray.

5. With the microliter syringe, deposit the challenge of particles a few centimeters in front of the leading edge of the sled.

6. Using the dispenser, place the desired volumetric challenge of water, $v_c$, on top of the particles.

7. Using the string, pull the sled at a rate of about 25 cm/s through the water and along the long axis of the tray, a distance of approximately 36 cm. Remove the sled from the tray.

8. Remove the folded wiper from the sled, determine its DWE as described in the preceding section.

9. Add a known volume of clean water to the tray (200 mL to 1000 mL is convenient) and determine the concentration of particles in the 1.0 μm to 3.0 μm range; after subtracting the background concentration, determine the number of particles remaining from the challenge.

10. Repeat for different values of $v_c$.

11. Calculate the particle removal ability (PRA), the number of particles remaining from the challenge (which includes some contributions from the wiper) for each value of $v_c$.

PRA can be presented as a function of the absolute volume of the challenge, $v_{c,}$ and as a function of the challenge relative to $A_i$. The relative challenge is expressed as $100\ v_c/A_{ip}$

## EXAMPLES 1- 9

The following materials were subjected to the dynamic testing methods with the results as achieved presented further below.

Example 1 was DURX™ 670, a hydroentangled, nonpatterned nonwoven fabric of 55% wood pulp and 45% (poly)ethyleneterephthalate having an average basis weight of 70.6 grams per square meter ($g/m^2$). The material is available from Berkshire Corporation, Great Barrington, MA.

Example 2 was MICROFIRST™, a hydroentangled, 24-mesh patterned nonwoven fabric of 45% wood pulp and 55% (poly)ethyleneterephthalate having an

average basis weight of 54.2 g/m$^2$. The material is available from Berkshire Corporation.

Comparative Example 3 was SUPERPOLX 1200™, a cleanroom laundered, knitted, fabric of 100% (poly)ethyleneterephthalate having an average basis weight of 154 g/m$^2$ and with unsealed edges. The material is available from Berkshire Corporation.

Example 4 was DyNamix™ 4990Q, a hydroentangled, 40-mesh patterned nonwoven fabric of 42% lyocell and 58% (poly)ethyleneterephthalate having an average basis weight of 75.2 g/m$^2$. The material is available from Berkshire Corporation.

Example 5 was DyNamix™ 6900Q, a cleanroom laundered, hydroentangled fabric of 100% (poly)ethyleneterephthalate having an average basis weight of 112 g/m$^2$. The starting nonwoven fabric is Sontara® 8007 which was cleanroom laundered as indicated below. The laundered material DyNamix™ 6900Q is available from Berkshire Corporation.

Comparative Example 6 was TexWipe® TX309, a woven fabric of 100% cotton having an average basis weight of 173 g/m$^2$. The material is available from The Texwipe Company, Upper Saddle River, NJ.

Comparative Example 7 was Alpha 10® TX1010, a cleanroom laundered, knitted, fabric of 100% (poly)ethyleneterephthalate having an average basis weight of 141 g/m$^2$ and with sealed edges. The material is available from the Texwipe Company.

Comparative Example 8 was PROWIPE 880, a spunbonded fabric of 100% (poly)propylene having an average basis weight of 85.9 g/m$^2$. The material is available from Berkshire Corporation.

Example 9 was DyNamix™ 5900Q, a hydroentangled fabric of 100% lyocell having an average basis weight of 102 g/m$^2$. The material is available from Berkshire Corporation.

With regard to cleanroom laundering, there are various cycles used by those having skill in the art. It was found that using a fabric having a relatively high basis weight of at least about 102 g/m$^2$ could withstand a cleanroom laundering/drying cycle. This process included agitating the fabric in hot water (minimum 120 ° F (49 °C)) with a non-ionic surfactant (about 1.8 gallons of water/pound of fabric (15 liters/kilogram)). The hot water had been purified by a reverse osmosis treatment and had a conductivity of 4 to 6 micromhos/cm. The fabric was rinsed in deionized water (about 1.2 gallons of water/pound of fabric (10 liters/kilogram)). The deionized water had a resistance of about 18

megohms/cm. Both types of water are filtered to 0.2 microns. Total wash time was limited to about 40 minutes, maximum.

The sorptive capacity and the releasable particles were determined for each example using the Po test which is found in IEST-RP-CC0004.2. The results are presented in the following table. It is further noted that the following results were for particles in the 1-3 micrometer range. Sorptive capacity is expressed in mL/g and releasable particles as $10^6/m^2$.

Table 1

| Example | Basis Weight ($g/m^2$) | Sorptive Capacity (mL/g) | Releasable Particles ($10^6/m^2$) |
|---|---|---|---|
| 1 | 70.6 | 4.36 | 1.53 |
| 2 | 54.2 | 5.26 | 1.13 |
| 3 | 154 | 3.13 | 1.00 |
| 4 | 75.2 | 5.42 | 0.341 |
| 5 | 112 | 3.89 | 0.830 |
| 6 | 173 | 1.48 | 24.8 |
| 7 | 141 | 2.58 | 0.663 |
| 8 | 85.9 | 5.20 | 1.89 |
| 9 | 102 | 6.48 | 2.84 |

The samples were tested for DWE using the method as described above. Most of the wipers were challenged with volumes of 2.00, 5.00, 10.0, 15.0, 20.0 and 30.0 mL, as well as with a volume calculated to be well in excess (approximately 130%) of the sorptive capacity of the respective wiper. For the sake of convenience, only challenge volumes of 10 milliliters (mL) and approximately 130% of sorptive capacity were reported for this portion of the examples. The challenge volumes were converted to a percent-of-capacity basis by dividing by the sorptive capacities of the individual plies. The actual amount of liquid sorbed for each sample is presented and is also expressed as a percentage of the challenge volume. Tables 2 and 3 present data for challenge volumes of 10 milliliters (mL) and approximately 130% of sorptive capacity, respectively.

Table 2

| Example | capacity | % capacity | liquid sorbed | |
|---|---|---|---|---|
| | mL/ply | for 10mL | mL | % |
| 1 | 15.6 | 64.1 | 9.41 | 94.1 |
| 2 | 14.4 | 69.4 | 8.96 | 89.6 |
| 3 | 23.5 | 42.6 | 9.89 | 98.9 |
| 4 | 21.3 | 46.9 | 9.18 | 91.8 |
| 5 | 22.4 | 44.6 | 9.84 | 98.4 |
| 6 | 12.3 | 81.3 | 8.38 | 83.8 |
| 7 | 16.3 | 61.3 | 8.40 | 84.0 |
| 8 | 23.4 | 42.7 | 4.35 | 43.5 |
| 9 | 34.8 | 28.7 | 9.90 | 99.0 |

Table 3

| Example | capacity of ply, $A_{ip}$ | liquid challenge | | liquid sorbed | |
|---|---|---|---|---|---|
| | mL/ply | mL | % | mL | % |
| 1 | 15.6 | 20.0 | 128 | 15.6 | 78.0 |
| 2 | 14.4 | 20.0 | 138 | 15.7 | 78.5 |
| 3 | 23.5 | 30.0 | 128 | 25.4 | 84.7 |
| 4 | 21.3 | 27.0 | 128 | 22.7 | 84.0 |
| 5 | 22.4 | 29.0 | 129 | 20.3 | 70.0 |
| 6 | 12.3 | 16.0 | 130 | 11.3 | 70.6 |
| 7 | 16.3 | 21.0 | 129 | 16.8 | 80.0 |
| 8 | 23.4 | 30.0 | 128 | 7.70 | 25.7 |
| 9 | 34.8 | 45.0 | 129 | 35.7 | 79.3 |

The samples were tested for PRA using the method as described above. The wipers were challenged with the same series of volumes as described in the test for DWE, except that each challenge volume was dosed with the ten million poly(styrene) spheres. The results for challenge volumes of 10 mL and approximately 130% of sorptive capacity are presented in Table 4 as number of particles remaining. Expressing this same data as a percentage of particles removed yields an expression of particle removal efficiency (PRE). These re-stated data are shown in Table 5.

Table 4

| | 2 mL | 5 mL | 10 mL | 15 mL | 20 mL | 30 mL | 130% capacity |
|---|---|---|---|---|---|---|---|
| 1 | 3.2 | 25 | 41 | 43 | 200 | - | 200 |
| 2 | 4.5 | 8.9 | 78 | 98 | 170 | - | 170 |
| 3 | 51 | 59 | 73 | 92 | 98 | 340 | 340 |
| 4 | 5.7 | 5.7 | 8.6 | 50 | 53 | - | 103 |
| 5 | 5.7 | 11 | 11 | 19 | 22 | - | 315 |
| 6 | 18 | 16 | 56 | - | - | - | 759 |
| 7 | 140 | 160 | 210 | 180 | - | - | 333 |
| 8 | 280 | 460 | 620 | 740 | 2800 | 3100 | 3100 |
| 9 | 0.6 | - | 3.9 | - | 11 | 7.8 | 180 |

Table 5

| | 2 mL | 5 mL | 10 mL | 15 mL | 20 mL | 30 mL | 130% capacity |
|---|---|---|---|---|---|---|---|
| 1 | 99.97 | 99.75 | 99.59 | 99.57 | 98.00 | - | 98.00 |
| 2 | 99.96 | 99.91 | 99.22 | 99.02 | 98.30 | - | 98.30 |
| 3 | 99.49 | 99.41 | 99.27 | 99.08 | 99.02 | 96.60 | 96.60 |
| 4 | 99.94 | 99.94 | 99.91 | 99.50 | 99.47 | - | 98.97 |
| 5 | 99.94 | 99.89 | 99.89 | 99.81 | 99.78 | - | 96.85 |
| 6 | 99.82 | 99.84 | 99.43 | - | - | - | 92.41 |
| 7 | 98.60 | 98.60 | 97.90 | 98.17 | - | - | 96.67 |
| 8 | 97.16 | 95.35 | 93.80 | 92.60 | 72.2 | 69.00 | 69.00 |
| 9 | 99.99 | - | 99.96 | - | 99.89 | 99.92 | 98.20 |

It was found that Example 5 exhibited very good properties conducive to critical cleanroom wiping applications, especially as tested by the newly developed methods. Also, the hydroentangled lyocell fabric of Example 9 was found to be an excellent candidate for critical cleanroom applications, particularly in dynamic wiping efficiency (DWE). Further, the results of the particle removal ability (PRA) tests showed that hydroentangled fabrics of pulp/polyester (Examples 1 and 2) and lyocell/polyester (Example 4)had surprisingly higher ratings especially when tested at volumes of challenge liquids that exceeded the intrinsic sorptive capacity of the material. These examples of low-cost hydroentangled fabrics represent a significant advance for general wiping

applications and, particularly for use in the critical cleanroom applications. The subject nonwoven fabrics equal and often exceed the performance of knitted fabrics in the comparative exmples that heretofore were considered the industry standard, especially in cleanroom applications.

It is also noted that a meltspun nonwoven fabric having substantially continuous filament polymer fibers would be useful in the subject invention. Such fabrics have continuous filaments, as do the aforementioned knitted fabrics. The polymer fibers can be polyesters or polypropylene or bicomponent fibers of polyester and polypropylene as described in co-pending U.S. Patent Application with Docket Number SS-2911, filed on Decmber 20, 1999 and also assigned to DuPont.

EXAMPLES 10 - 13

Inventive Example 10 is a cleanroom laundered DyNamix™ 6900QL as used in Example 5, above. Comparative Example 11 is Sontara® style 8007, which is essentially the same fabric as in Example 10 except that it was not cleanroom laundered. Comparative Example 12 was Sontara® style 8000 with a low basis weight of 39.9 g/m$^2$ that was not laundered, but treated with surfactant to improve its sorptive properties. Comparative Example 13 is SUPERPOLX 1200, a polyester knit having been cleanroom laundered as in Example 3, above.

The examples were tested for various static properties using the test as described above, as well as the DWE and PRA tests. The results are presented in Table 6

Table 6

| Example | 10 | 11 | 12 | 13 |
|---|---|---|---|---|
| **Basis wt, $g/m^2$** | 113 | 110 | 39.9 | 142 |
| **Fibers/$cm^2$** | 1.3 | 4.2 | 24 | 0.26 |
| **Particles** | | | | |
| biaxial shake, $10^6/m^2$ | 18 | 10 | 270 | 16 |
| **Absorbency, $cc/m^2$** | 627 | 510 | 232 | 469 |
| **Specific Absorbency, cc/g** | 5.5 | 4.6 | 5.8 | 3.3 |
| **Time to ½ Sorption, s** | 1 | >300 | 2 | 1 |
| **Ions, ppm** | | | | |
| Na | 0.5 | 8.4 | 66 | 0.31 |
| K | 0.16 | 1.4 | 2.3 | 0.12 |
| Ca | 0.16 | 22 | 18 | 0.11 |
| **DWE**, @ 10 mL challenge, % | 98.4 | 25 | 1 ply 3 ply<br>94.7 99.7 | 98.9 |
| **PRA** 10 mL challenge, $10^3$ Part. Left on surface | 11 | 5310 | 1 ply 3 ply<br>498 13.6 | 73 |

The inventive Example 10 exhibits excellent cleanliness data, low fiber shedding, and excellent sorbency. It also exceeds the unlaundered example in ion contamination.

Comparative Example 11 is reasonably clean based on biaxial shake number, but exhibits medium to high fiber shedding, and very poor sorbency.

Comparative Example 12 is deficient by comparison in particle burden, sorbency capacity and rate, extractable matter, and ion burden. The treatment with surfactants, while helpful in increasing sorptivity, resulted in greater amounts of undesirable ions. However, it is surprising that when used in a 3-ply structure, the fabric exhibited a PRA near that of inventive Example 10.

Comparative Example 13 is similar to the inventive fabric in terms of biaxial shake particles and ions. Being continuous filament, it excels in low fiber shedding, but it did not perform as well as the inventive fabric in sorptive capacity.

The Particle Removal Ability results show the superior cleaning ability of the inventive fabric of Example 10, which left only 11,000 particles from a 10 million-particle challenge compared to 5.3 million particles left by its unlaundered counterpart, Comparative Example 11. Particularly relevant is that Example 10 out-performed Comparative Example 13, which left 73,000 particles in its wake. It is especially surprising that the inventive fabric combined excellent cleanliness properties as determined by conventional static means, as well as superior sorptive properties and excellent performance in particle removability (functional cleanliness).